REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
27 October 1999

3. REPORT TYPE AND DATES COVERED
Final Report, 1 Jun 99 - 30 Sep 99

4. TITLE AND SUBTITLE
Improved GPS Analysis and Data Fusion for Ionosphere World Day Campaigns Near Puerto Rico (Final Report)

5. FUNDING NUMBERS
Contract N00014-99-M-0158

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8. PERFORMING ORGANIZATION REPORT NUMBER

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Program Officer (Attn: Robert McCoy, ONR321SR)
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800 North Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
CLIN/SLIN 0001AB

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unlimited distribution

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Discrete inverse theory (DIT) and the RIBG model are used to process dual frequency GPS data. Differential Bias values are obtained for each receiver-satellite pair. Final Bias results are obtained as the median of daily Bias value solutions for the preceding week. Subtracting a median Bias value from shifted differential phase pseudorange data yields slant total electron content (TEC) data for input to an assimilating physical ionospheric propagation model (AIPM). Such data is processed to obtain driving parameters of the ionospheric model for near-real-time regional ionospheric specification. We illustrate this with RIBG, with its sunspot number (SSN) driving parameter, in the context of regional specification by a network of GPS receivers. The RIBG/DIT method is applied to Puerto Rico (PR) experiment data for June 23-29, 1998 and September 1-15, 1999 for several GPS receivers and satellites. Median differential biases, SSN values, and foF2 predictions from RIBG are compared with those from the conventional method, which maps an adjustable vertical TEC parameter to slant TEC by means of a spherical ionospheric shell. The RIBG results are found to be much more accurate, judging by transportability of SSN values to adjacent GPS stations, reasonability of the SSN values, and comparisons of foF2 predictions with ionosonde data. We provide GPS differential Bias values for the PR experiments. We discuss implications for ionospheric specification, development of an AIPM model, military navigation, and military systems.

14. SUBJECT TERMS
GPS, Ionospheric specification, RIBG, data assimilation, differential biases, discrete inverse theory

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclasssified	Unclassified	Unclassified	UL

FINAL REPORT
CLIN/SLIN 0001AB on Contract N00014-99-M-0158

To:
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Title

Improved GPS Analysis and Data Fusion for Ionosphere World Day Campaigns Near Puerto Rico

By

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October 16, 1999

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FINAL REPORT FOR AWARD #: N00014-99-M-0158

Improved GPS Analysis and Data Fusion for Ionosphere World Day Campaigns Near Puerto Rico

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Long-term Goals: (1) Develop environmental (especially ionosphere, but also troposphere for low elevation angle effects) propagation models which can, in combination with remote and in-situ ionospheric sensor measurements, determine in near-real-time (NRT) the global radio propagation environment. (2) Establish the role of GPS, in combination with other sensors, for updating in NRT an assimilating physics-based ionospheric propagation model (AIPM) for global specification of the electron density distribution and atmospheric compensation in radio systems. (3) Establish the functionality of this data fusion technique in the overall space weather computational system (SWCS). (4) Help determine the functionality of the SWCS for solar-terrestrial physics development and for atmospheric compensation in high-performance radio systems.

Scientific Objectives: The stated objectives of this contract are as follows. **(1)** Further develop techniques for GPS data analysis for ionospheric specification, comparing with results from other ground-based sensors and extending the analysis to the September, 1999 Puerto Rico data campaigns. **(2)** Demonstrate improved ionospheric specification by suitably amending the ionospheric model. **(3)** Develop a data fusion scheme, combining GPS with other data sets, for improved ionospheric specification.

Approach:

Scientific Objective **(1)**: Further develop techniques for analysis of GPS ground-based receiver data for ionospheric specification. This includes comparison with other ground-based sensor results and extension of analysis from the June, 1998 Puerto Rico experiment campaigns to the September, 1999 Puerto Rico experiment. In our previous reports [Reilly and Singh, 1999], we compared three methods, referring to them as Methods 1-3, for calculating differential hardware biases from dual frequency GPS shifted differential phase pseudorange data. We concluded that only Methods 1 and 3 were worth pursuing.

In Method 1 [Coster, 1999], the traditional approach, the ionospheric contribution to differential phase pseudorange data is proportional to the total electron content (TEC), which is modeled as the product of a constant vertical total electron content (VTEC)

value and a mapping factor (from VTEC to TEC). The mapping factor is associated with a spherical ionospheric shell model at a fixed height (commonly 350 km.). It changes over time with the satellite geometry. The unknown model parameters, VTEC and differential hardware bias terms for each satellite, are obtained from a discrete inverse theory (DIT) analysis [Menke, 1989] of GPS data from a ten-minute time interval. This procedure produces hardware bias solutions that are quite stable from day to day (±2 TEC units for a one-week period).

In Method 3, the ionospheric contribution is proportional to the line-of-sight TEC of the RIBG climatological ionospheric propagation model [Reilly, 1993; Reilly and Singh, 1997], where ray tracing in this application is simplified greatly by the line-of-sight assumption. The unknown model parameters, an effective sunspot number (ssne or SSN) driving parameter of the RIBG ionospheric model and the differential hardware biases for each satellite, are obtained from DIT analysis of GPS data for a two-hour time interval. Method 3 differential hardware bias solutions occasionally show erroneously large day-to-day variations, so-called data "outliers". A procedure was suggested [Reilly and Singh, 1999], whereby median values of hardware biases would be selected from a one-week running history of hardware bias solutions, which would essentially eliminate the outlier problem. This would be followed by a DIT recalculation of the single ssne driving parameter unknown for RIBG.

For specificity, we review the formulae for determination and use of the hardware biases for ionospheric specification by the Raytrace/ICED-Bent-Gallagher (RIBG) model. The two-frequency GPS receiver measures both phase and code pseudorange (phase and group path lengths) to each of several satellites in view for both L1 and L2 frequencies. Differential phase and code pseudoranges to a satellite are found by taking L1-L2 and L2-L1 differences, respectively. After correcting for phase cycle slips, a differential phase time arc is obtained that appears to be a smooth version of the differential code pseudorange curve, because of the absence of multipath effects in the differential phase arc, but is shifted above or below it, corresponding to a residual phase integer ambiguity. The differential phase arc is then shifted to agree in the mean with the differential code arc and is used thereafter in the analysis as a smoothed differential code arc, which is modeled as usual, but without the multipath contribution. The initial uncertainty in this procedure is 0-2 total electron content (TEC) units (TECU), where 1 TECU = 10^{16} m^{-2}, depending on the average magnitude of the multipath contribution during the time arc. The differential hardware bias for each satellite (Bias), which is associated with the difference between satellite and receiver clock offsets, is obtained by applying discrete inverse theory (DIT) [Menke, 1989] to the equation

$$9.5175(\Delta R) - TEC(SSN_0) = \frac{d(TEC)}{d(SSN)}\delta(SSN) + Bias \qquad \text{(Finds Bias values)} \qquad (1)$$

where the first term on the left is the shifted phase pseudorange arc in TECU (the shifted differential phase pseudorange ΔR is in meters), and the line-of-sight TEC for the estimated RIBG sunspot number SSN_0 driving parameter is subtracted from it to form the modified observable for the iteration. The right side is linear in the unknowns, which are the Bias and the difference between the solution for SSN and its estimate. DIT iterates

equations of this form for five satellites and for about two hours worth of data at 30-second intervals, in order to obtain stable convergence to the values of SSN and Bias values. This is Method 3 for obtaining the Bias values. The traditional Method 1 eliminates the TEC(SSN_0) term on the left in Eq. (1) and substitutes $(MF)VTEC$ for the first term on the right in Eq. (1), where the mapping factor MF is the secant of the angle of incidence of the ray on a spherical ionospheric shell at height 350 km. and VTEC is the vertical TEC unknown, assumed constant in the vicinity of the receiver. In Method 1 there are no iterations and only 10 minutes worth of data from five satellites are required to obtain a stable solution. Although Method 1 has some convenience advantages over Method 3, the overriding consideration is accuracy of the Bias values, and this will be seen to favor Method 3.

Once the Bias values are determined, the experimental slant TEC data is obtained by simply subtracting the Bias values from the shifted differential phase pseudorange time arcs. This data is valuable for development of AIPM models, currently in progress, if the Bias values are accurate, as from Method 3. Presently, ionospheric specification and atmospheric compensation in radio systems is obtained from RIBG and GPS data by using median Bias values for the preceding week to recalculate the SSN driving parameter. DIT is used to solve for SSN from Eq. (1), with the known median Bias value brought over from the right side to the left side, as part of the modified observable.

Analysis of the June, 1998 Experiment

Figures 1-3 show the biases from Method 3 in TEC units vs. day number and both the average or mean values and the median values for one week in June, 1999 for Richmond, Isabella, and Bogota stations, whose coordinates are given in Table 1.

Table 1. Coordinates of GPS Receiver Stations for the Puerto Rico Experiments

Stations	Latitude (° N)	Longitude (° W)
Richmond, Fl.	25.613	80.383
Isabella, PR	18.340	67.066
Bogota, Colombia	4.640	74.080
Kourou, Fr.Guy.	5.252	52.806

Day 177 corresponds to June 26, 1998, and the time period shown is for the first Puerto Rico experiment that surrounded Ionosphere World days. The results show that there is occasionally a significant difference between the average and the median, particularly when there are large variations or outliers in the day-to-day variations. We prefer the median, because it is designed to minimize the impact of isolated data outliers. We shall generalize this to a trend line approach in the future. The results also show the potential importance of using the median bias, since large day-to-day variations are clearly artifacts of the solution procedure and cannot represent the relatively constant behavior of the actual differential hardware biases.

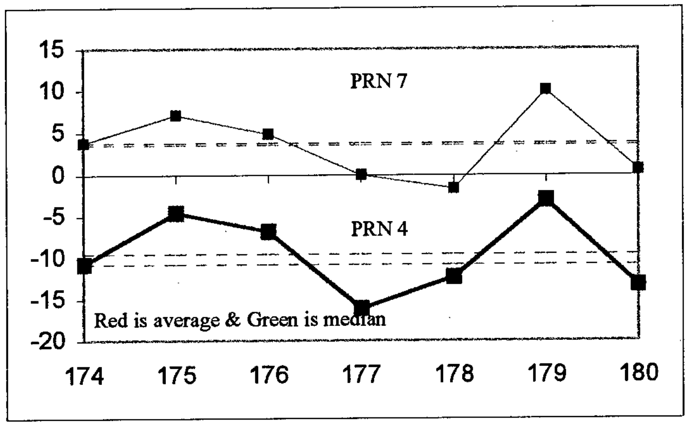

Figure 1a. Richmond biases by Method 3 in TECU for satellites PRN7 and PRN4. Days 174-180 correspond to June 23-29, 1998

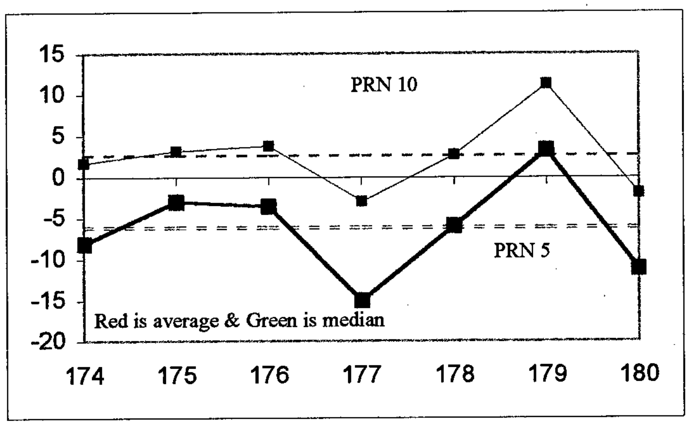

Figure 1b. Richmond biases by Method 3 in TECU for satellites PRN5 and PRN10. Days 174-180 correspond to June 23-29, 1998

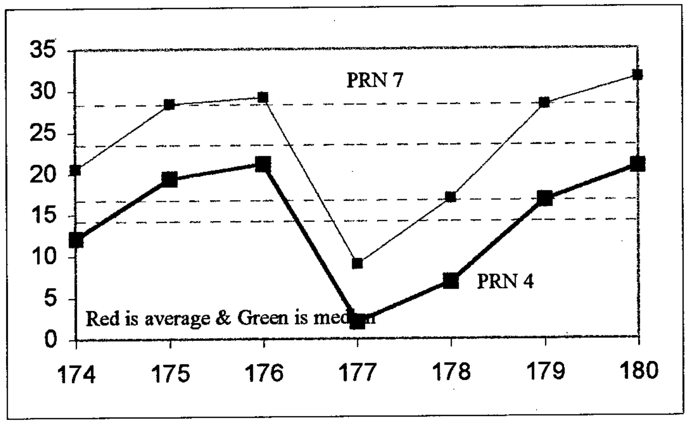

Figure 2a. Isabella biases by Method 3 in TECU for satellites PRN4 and PRN7. Days 174-180 correspond to June 23-29, 1998

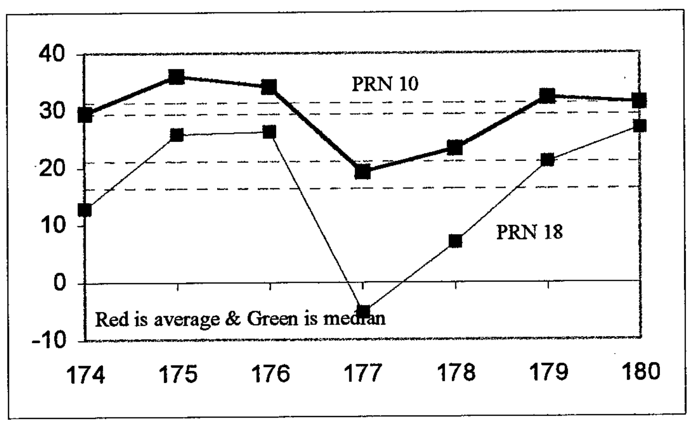

Figure 2b. Isabella biases by Method 3 in TECU for satellites PRN5 and PRN10. Days 174-180 correspond to June 23-29, 1998

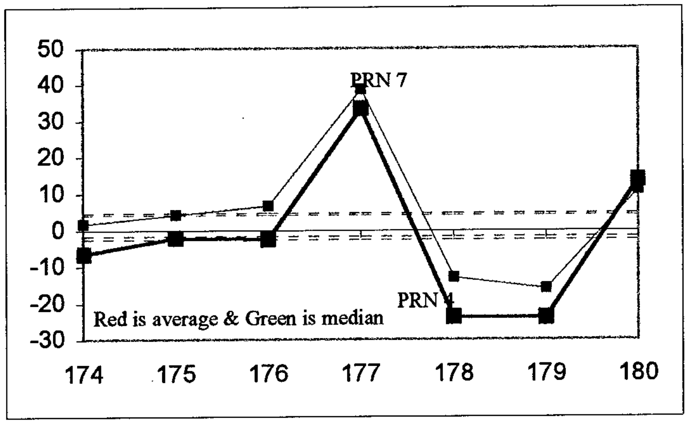

Figure 3a. Bogota biases by Method 3 in TECU for satellites PRN4 and PRN7. Days 174-180 correspond to June 23-29, 1998

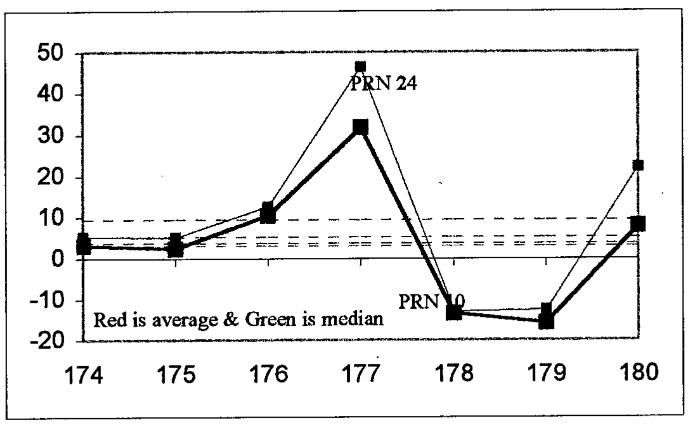

Figure 3b. Bogota biases by Method 3 in TECU for satellites PRN10 and PRN24. Days 174-180 correspond to June 23-29, 1998

The use of median biases is not as critical for Method 1, but some improvement could also be expected for this method. Witness the importance of median biases for Method 1 applied to the Kourou station in Fig. 4. In previous reports we had argued that its use would favor Method 3 over Method 1, based on the ability of processed data from one GPS station to predict the data at another GPS station. We now have additional data that verify the superiority of Method 3.

We recalculate RIBG SSN values for Richmond and Isabella stations, using the median biases in Table 2, obtained from Methods 1 and 3. Method 3 biases were shown in Figures 1 and 2. Method 1 biases are shown in Figures 5 and 6. These are midlatitude

Table 2. Comparison of Median Biases (TECU) from Methods 1 and 3 for Richmond and Isabella

	Richmond		Isabella	
SV	Method 1	Method 3	Method 1	Method 3
4	-5	-11	-1	17
5	-1	-6		
7	7	4	13	28
10	11	3	16	31
18			2	21

stations that are not too far apart, and so we do not expect large differences in SSN values for the two stations. For Richmond the Method 1 median biases in Table 2 tend to be more positive than Method 3 biases, by about 5 TECU on average, and so RIBG SSN values should turn out to be somewhat lower in Method 1 than in Method 3. On the other hand, for Isabella the Method 1 median biases are much lower than Method 3 median biases, by about 17 TECU on average, and so Method 1 SSN values should turn out to be much greater than Method 3 SSN values. Figures 7 and 8 show the results of SSN recalculation for Richmond and Isabella by using median biases from Methods 1 and 3. Evidently, the Method 3 curves for Isabella are much closer together on average, which is what we expect from the proximity of the stations. The Day 179 fluctuation indicates disturbed ionospheric behavior.

Independent verification of Method 3 biases is obtained from foF2 data. The foF2 values for the one-week period are shown in Figure 9 for a Puerto Rico ionosonde station. The ionosonde station is within few hundred kilometers of the Isabella GPS receiver. The TEC analysis in the previous figures was between 16 to 18 UT hours. The measured foF2 at 17 UT and that calculated by RIBG with the effective SSN values from Methods 1 and 3 are shown in Figure 10. This comparison clearly shows that Method 3 sunspot numbers are very close to realistic values. This agreement is especially gratifying, since we have introduced another error source. The model's fit to TEC data is converted to

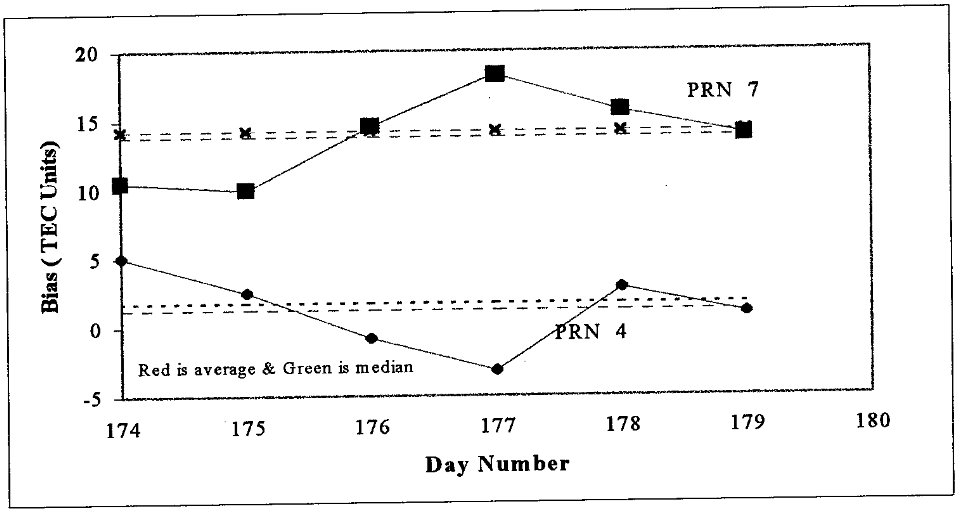

Fig. 4a. Kourou biases by Method 1 in TECU for satellites PRN4 and PRN7. Days 174-180 correspond to June 23-29, 1998.

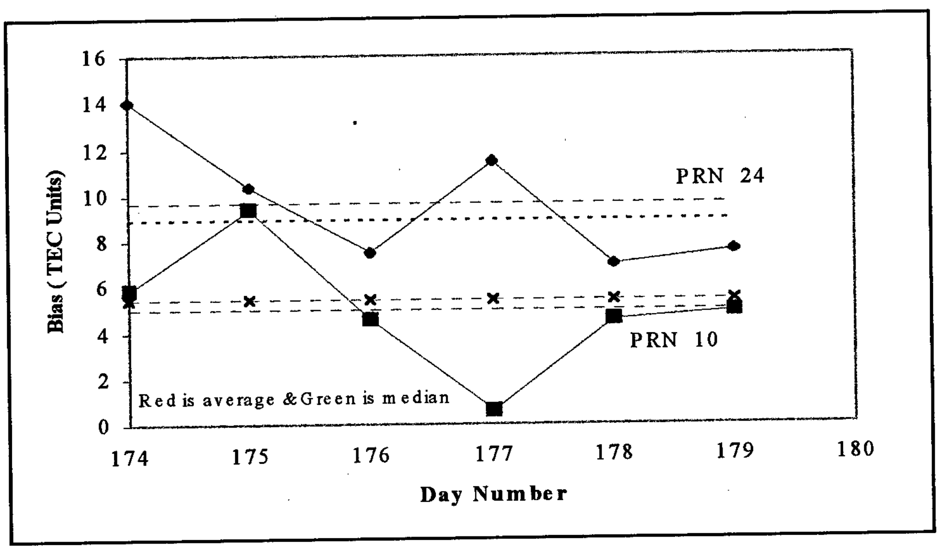

Fig. 4b. Kourou biases by Method 1 in TECU for satellites PRN10 and PRN24. Days 174-180 correspond to June 23-29, 1998.

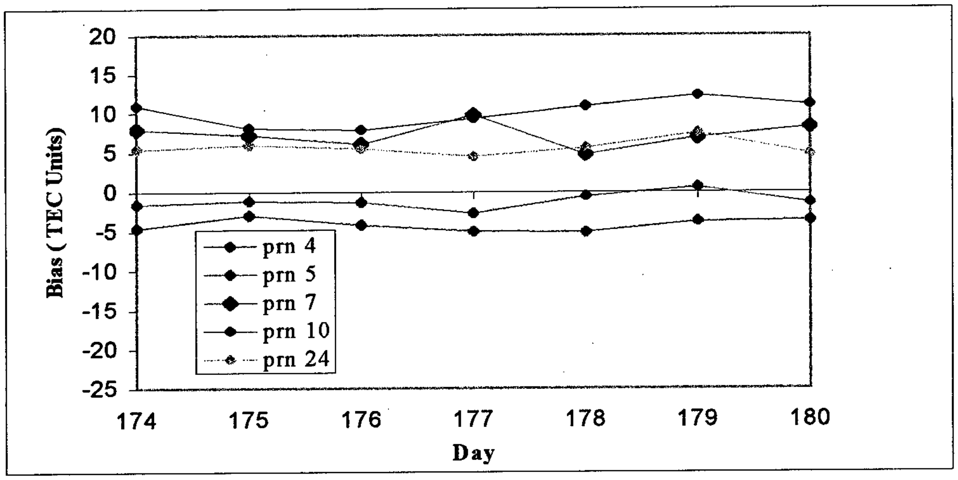

Fig. 5. Richmond biases by Method 1. Days 174-180 correspond to June 23-29, 1998.

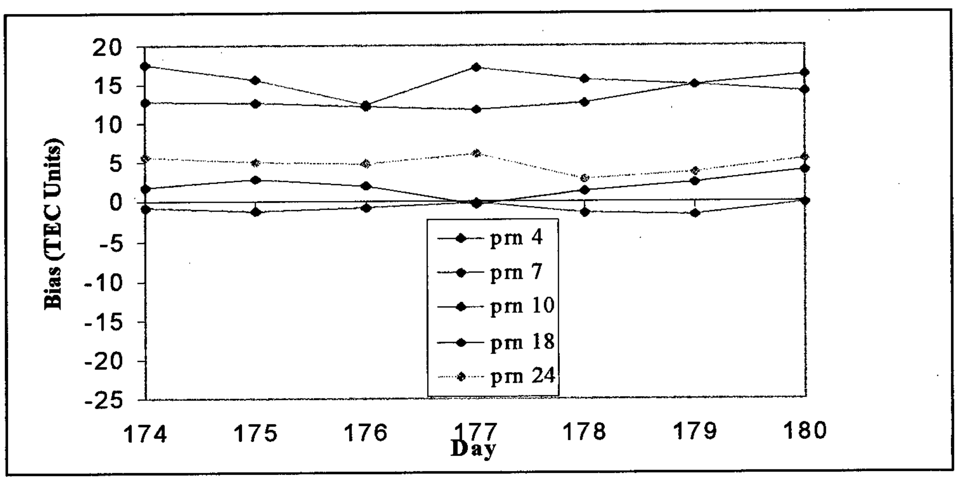

Fig. 6. Isabella biases by Method 1. Days 174-180 correspond to June 23-29, 1998.

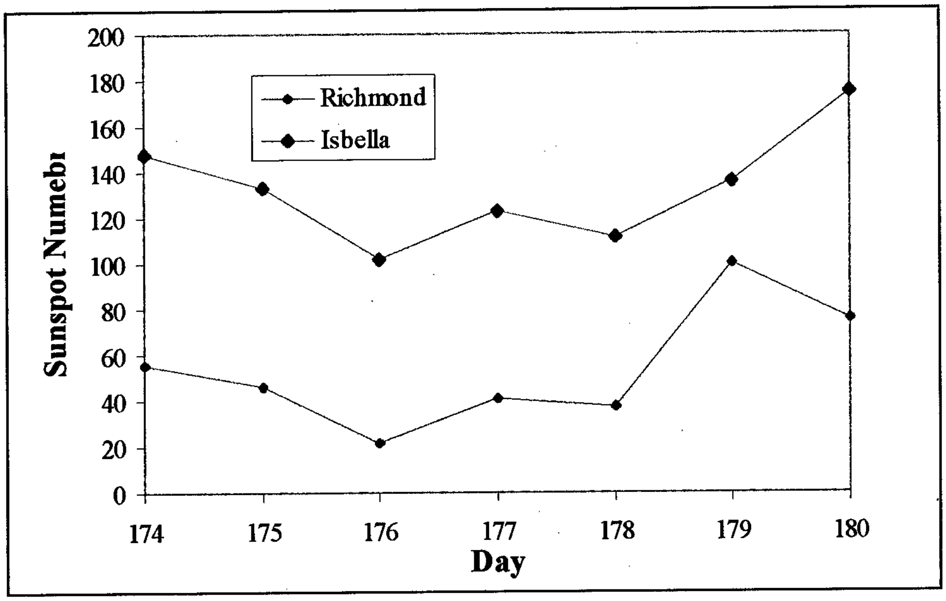

Fig. 7. Effective SSN values for Richmond and Isabella with Bias values from Method 1

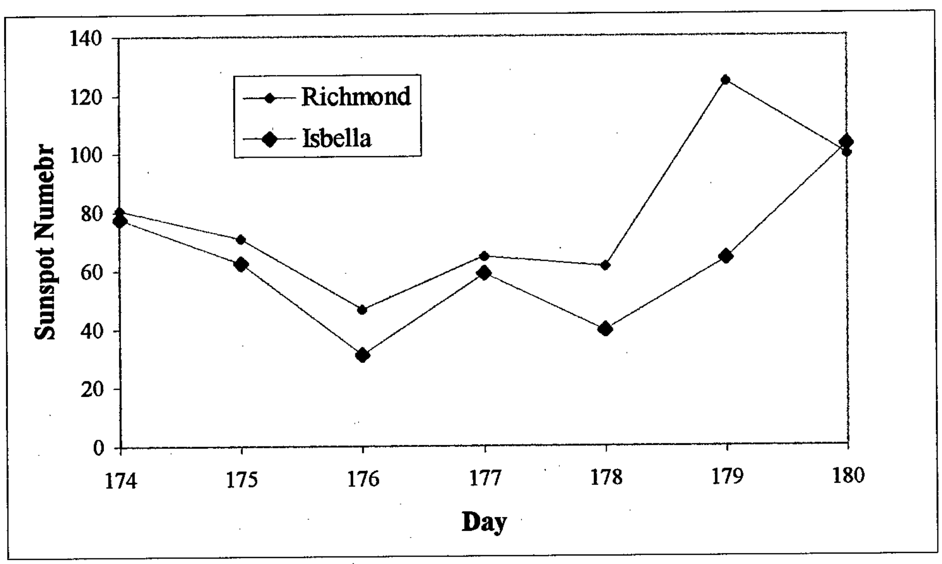

Fig. 8. Effective SSN values for Richmond and Isabella with Bias values from Method 3

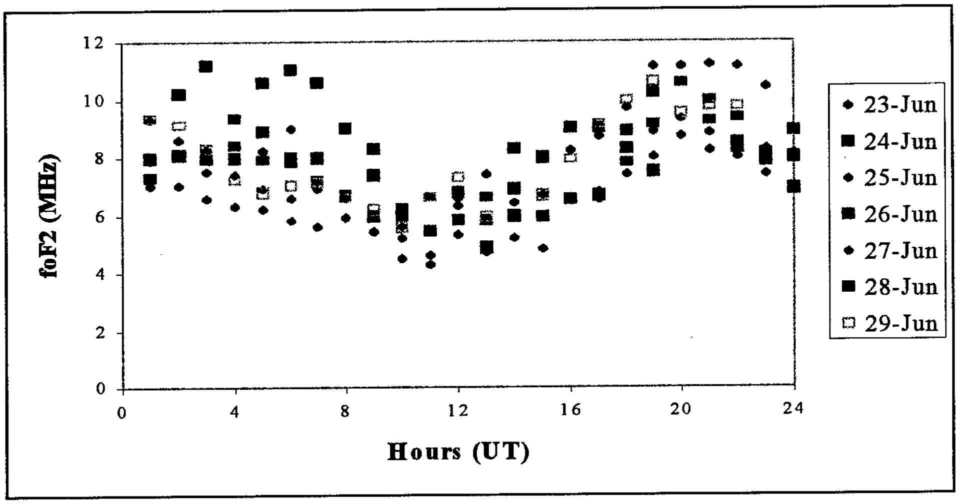

Fig. 9. Puerto Rico ionosonde data for foF2 for Puerto during 23 thru 29 June, 1999

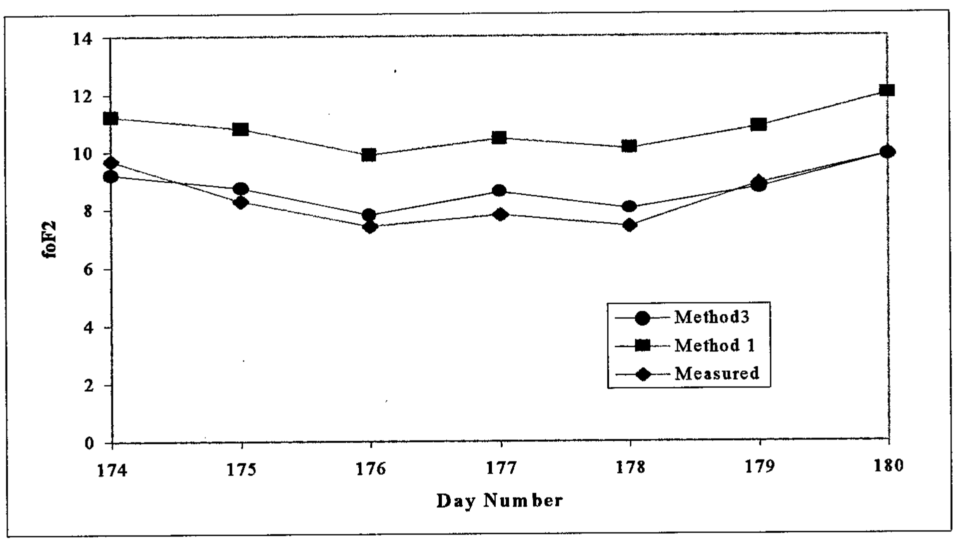

Fig. 10. Comparison of PR ionosonde foF2 data with Isabella values calculated from RIBG with effective SSN values from Methods 1 and 3 at 1700 UT

foF2 data easily through the solved SSN value, but we basically deconvolve the RIBG model's profile shape function out of the TEC fit to arrive at foF2.

Figures 7, 8, and 10 show that Method 3 biases are of high quality and lead to a scheme for ionospheric specification in a large region from RIBG in which effective SSN values obtained from a network of receivers could be interpolated to the points of interest. Such a scheme would apparently not work with Method 1. As we have already indicated, a set of accurate biases, which are obtained from Method 3, should prove valuable for collecting a slant TEC database for development of an AIPM.

It remains to see how well RIBG fits the shifted differential phase pseudorange data and whether or not this is another criterion for selection between Methods 1 and 3. Figures 11 and 12 show the goodness of fit for Isabella, where the SSN differences between Methods 1 and 3 are very large. Five satellites' data are shown, 240 points each (two hours at 30 second intervals), on two different days, one nominally geomagnetically quiet (day 174) and the other disturbed (day 177). Despite the disparity in SSN values between Methods 1 and 3, there is not a dramatic difference between them, based on goodness of fit. The fit is better for Method 3, which is significant, because it is this difference that enables the determination of Method 3 biases in the fitting process, but this is really only noticeable for two of the five satellites. An error in the bias solution is largely compensated for by an error in the SSN solution, which is to be expected from the fitting process. More dramatic affirmations of Method 3 arise from the transportability of the effective SSN value from one GPS station to another one relatively nearby and its ability to closely predict independent foF2 data.

So far, the success of the Method 3 biases has been demonstrated for a pair of midlatitude stations, although the Isabella station in Puerto Rico is only about 28° north of the geomagnetic equator. It is also of interest to test the Method 3 biases for Bogota and Kourou, which are in the equatorial anomaly and low latitude region. These stations are separated by about 21° in longitude (cf. Table 1), 1270 nautical miles, or 1.4 hrs. in local time. The median biases from Methods 1 and 2 for the week are given in Table 3. A

Table 3. Comparison of Median Biases (TECU) from Methods 1 and 3 for Bogota and Kourou.

SV	Bogota		Kourou	
	Method 1	Method 3	Method 1	Method 3
4	0.1	−2.5	1.8	3.8
7	8.4	4.1	14.2	27.3
10	8.5	3.1	8.9	21.4
24	6.6	5.2	9.6	10.1

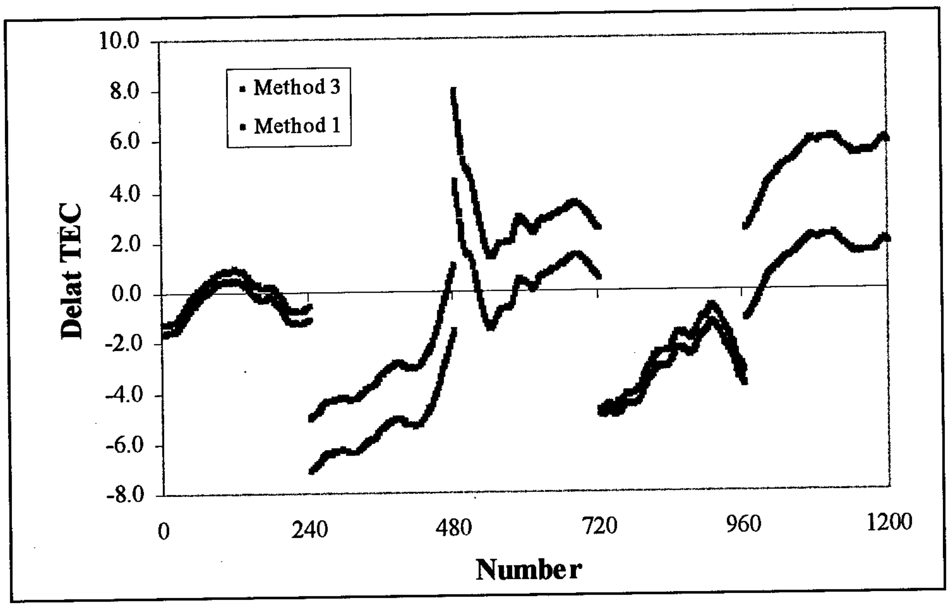

Figure 11. $Delta\ TEC = 9.5175(\Delta P) - TEC(SSN) - Bias$ for Isabella, day # 174

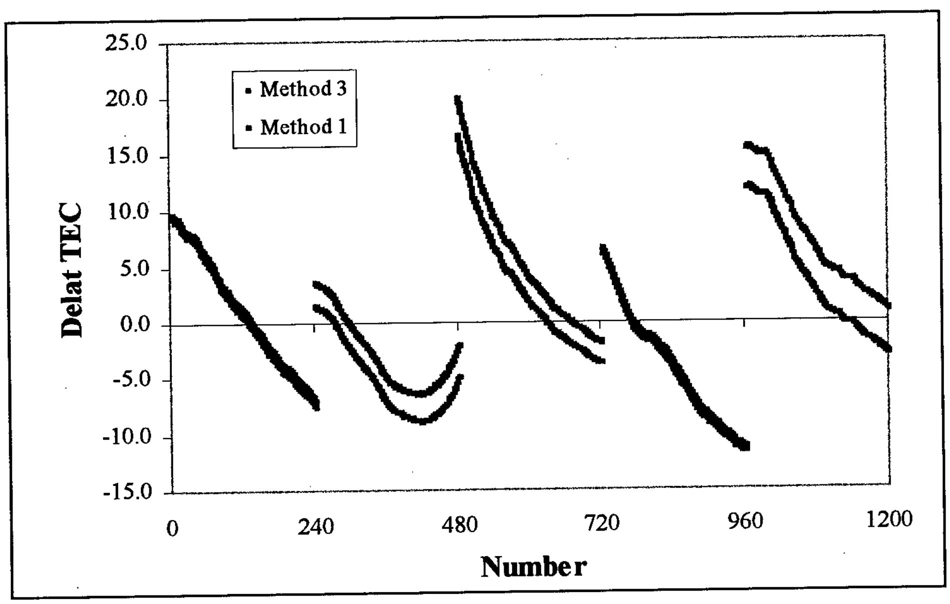

Figure 12. $Delta\ TEC = 9.5175(\Delta P) - TEC(SSN) - Bias$ for Isabella, day # 177 (disturbed)

recalculation of SSN values for the Bias values of Methods 1 and 3 are shown in Figures 13 and 14. Evidently, Method 3 SSN curves are much closer together on average than Method 1 curves, which again is expected of two GPS stations somewhat close to each other. This gives us confidence that Method 3 Bias values can be used for ionospheric specification and that the SSNE values for a network of receivers will be in proper relationship, to be able to correctly interpolate results to all interior points of the region. Method 3 SSN values are transportable to nearby GPS stations in this sense, whereas Method 1 values are not. The fluctuation away from this agreement in Fig. 14, as on Day 176, apparently corresponds to real ionospheric behavior.

Analysis of the September, 1999 Experiment

The second in the series of World Day experiments was held, beginning after the first week of September 1999. We started the analysis of GPS data for the Isabella GPS receiver from the first of September. This was done, so that the Bias values could be tracked for the experiment and one week before it. For each day of the period, the bias was computed for the day by computing the median value from the set of values for that day and the preceding six days. This sliding-window approach could used in operations. From these Bias values we recalculated sunspot numbers and associated foF2 values for all the available data during the week, covering all 24 hrs of the day. In the 1998 campaign we concentrated on two hours of the afternoon. We intend to compare our predictions of foF2 with Puerto Rico ionosonde data, which is not yet available at this writing.

A sampling of calculations is included in the figures below. Fig. 15-17 shows Isabella Bias values from Methods 1 and 3 for three different 2-hour intervals. Note how much smoother is the variation of sliding-window median Bias values, particularly for Method 3, as compared to the variations shown in Figures 1-3. The fluctuations indicate the precision of these biases, which appears to be within a few TEC units. Generally, Method 3 Bias values are substantially higher than Method 1 Bias Values, which means that SSN values recalculated from Method 1 median Bias values will be substantially greater than SSN values recalculated from Method 3 median Bias values. This is substantiated by Fig. 18, which compares recalculated SSN values from Methods 1 and 3. Method 3 SSN values are more in line with the ordinary Zurich sunspot numbers for this time period. RIBG is driven by these SSN values and can be used to predict any number of ionospheric or radio system parameters. In particular, Fig. 19 is a prediction of foF2 values from Methods 1 and 3, which will be compared with Puerto Rico ionosonde values, when they become available.

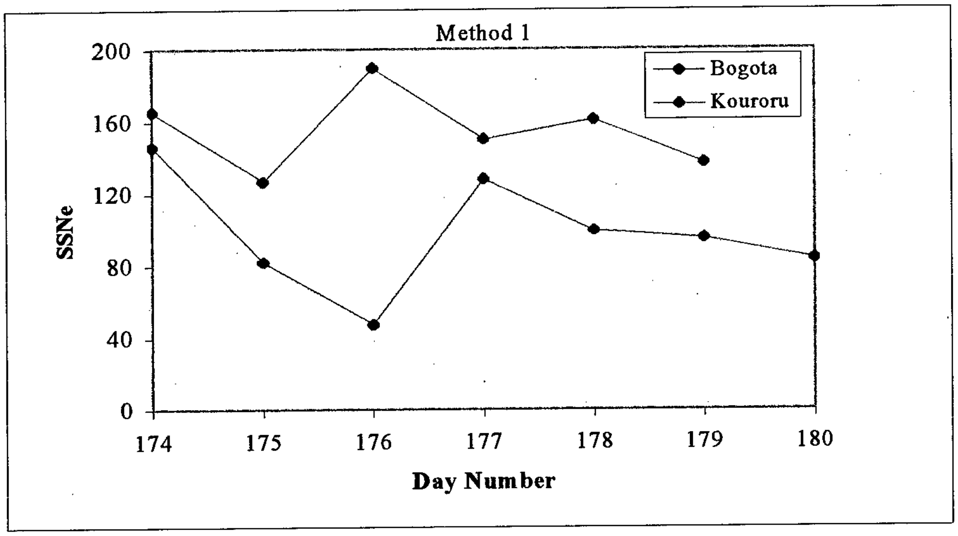

Fig. 13. Recalculated SSN curves for Method 1 median Bias values for Bogota and Kourou

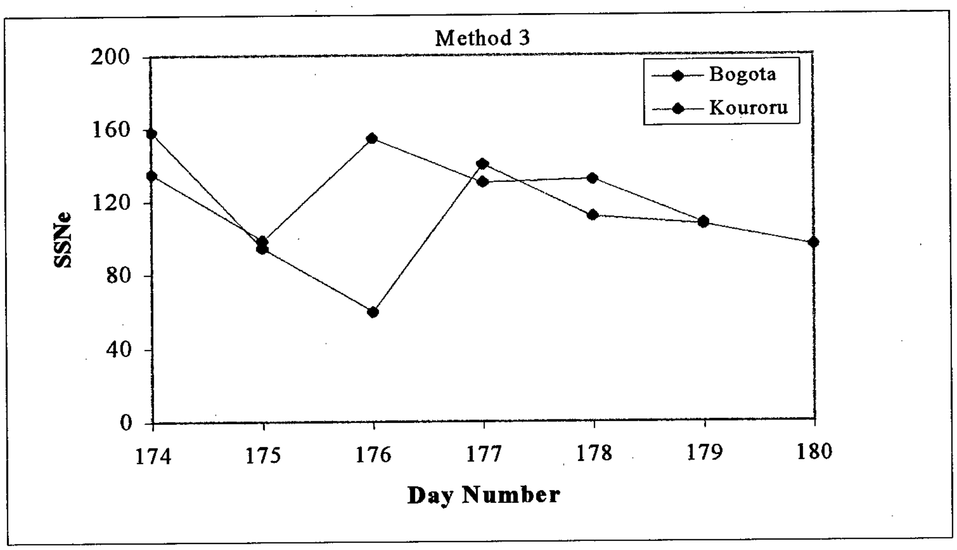

Fig. 14. Recalculated SSN values for Method 3 median Bias values for Bogota and Kourou

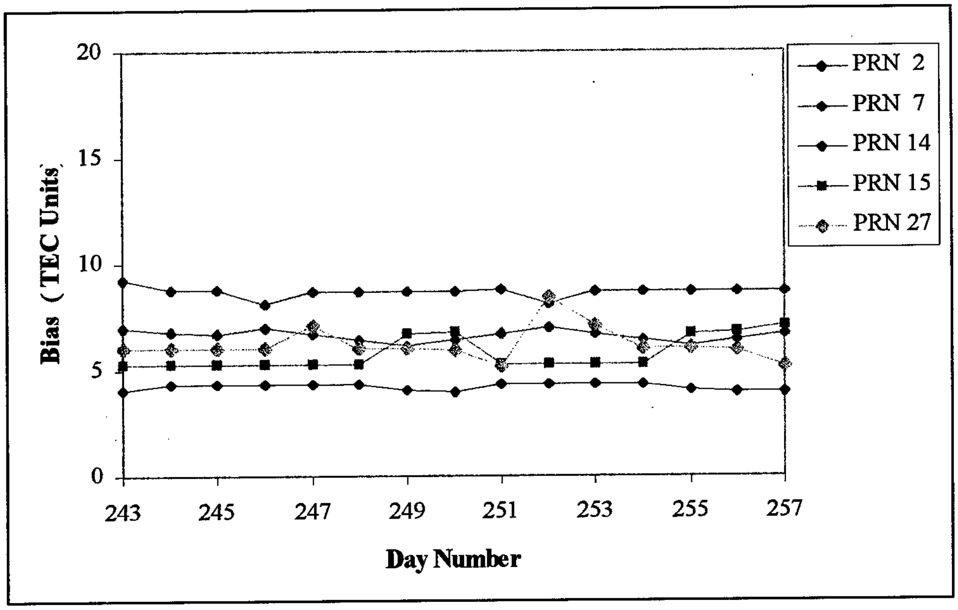

Fig. 15a. Sliding-median Bias values for Isabella during 06–08 UT from Method 1. Day 243 is Sept. 1, 1999

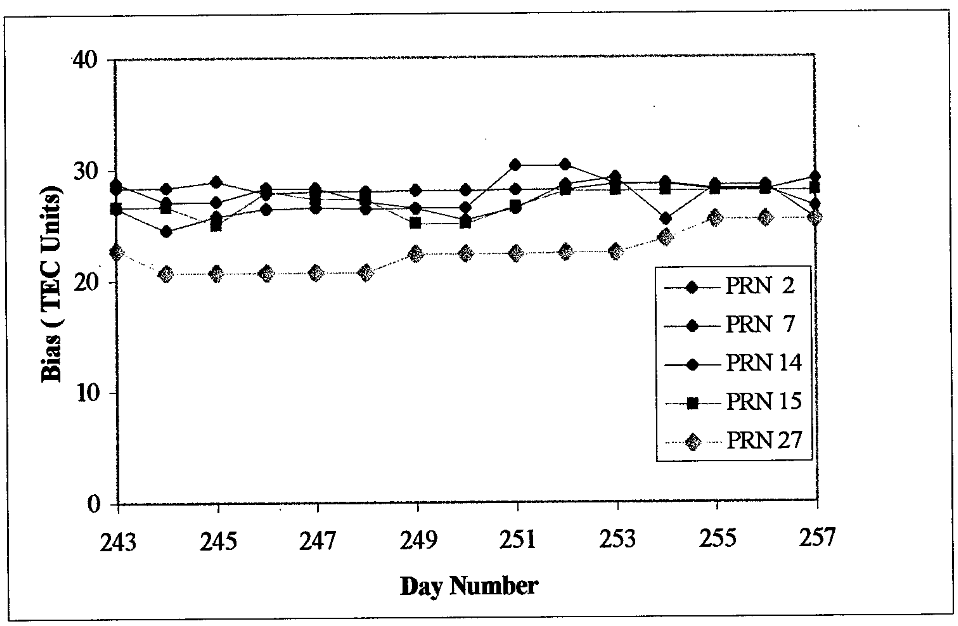

Fig. 15b. Sliding-median Bias values for Isabella during 06–08 UT from Method 3. Day 243 is Sept. 1, 1999

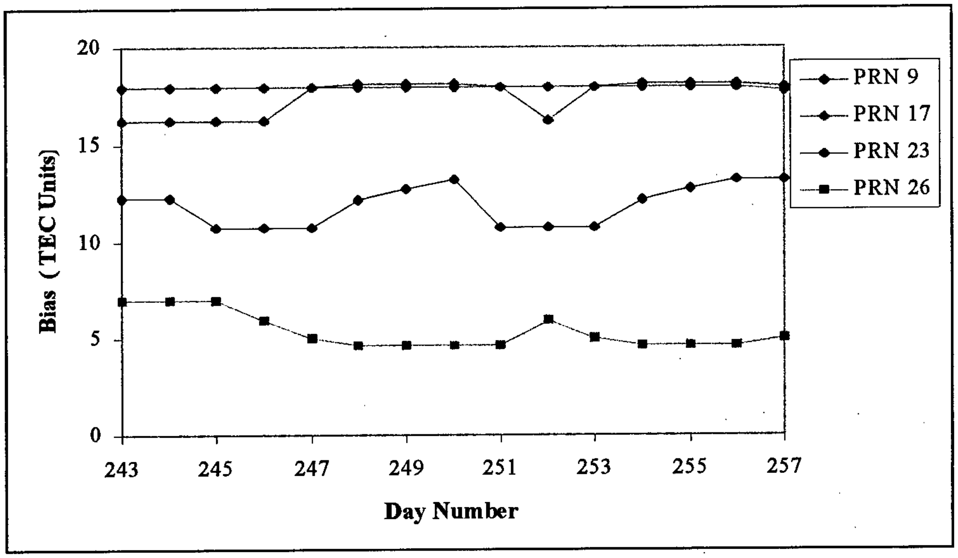

Fig. 16a. Sliding-median Bias values for Isabella during 16–18 UT from Method 1. Day 243 is Sept. 1, 1999

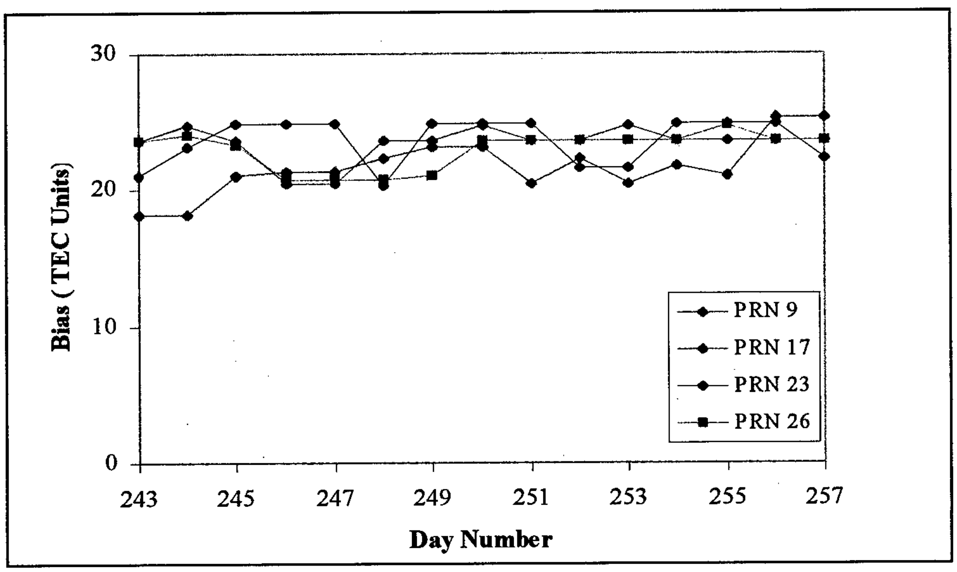

Fig. 16b. Sliding-median Bias values for Isabella during 16–18 UT from Method 3. Day 243 is Sept. 1, 1999

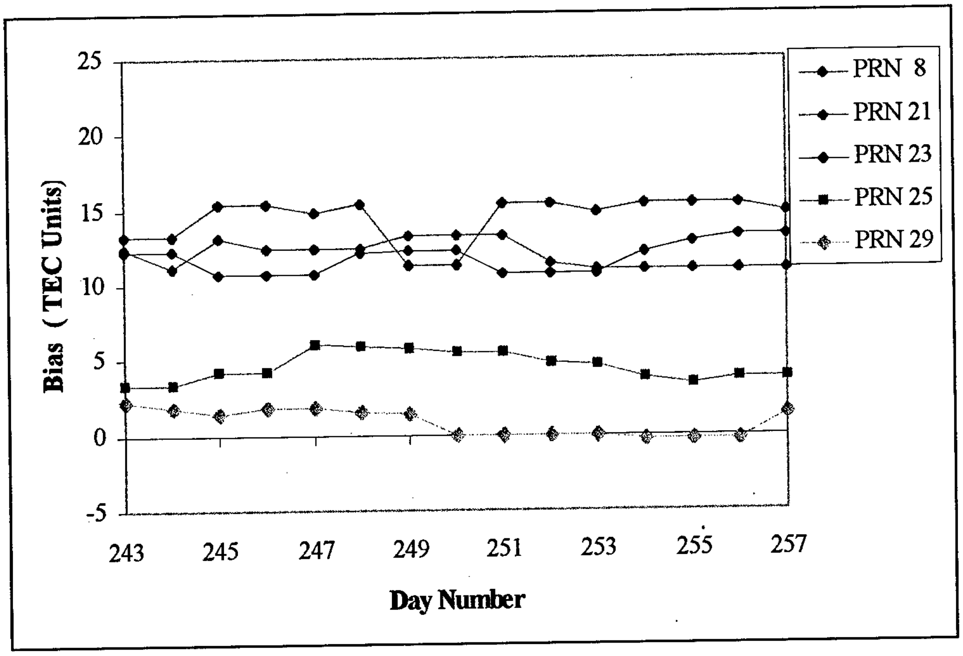

Fig. 17a. Sliding-median Bias values for Isabella during 20–22 UT from Method 1. Day 243 is Sept. 1, 1999

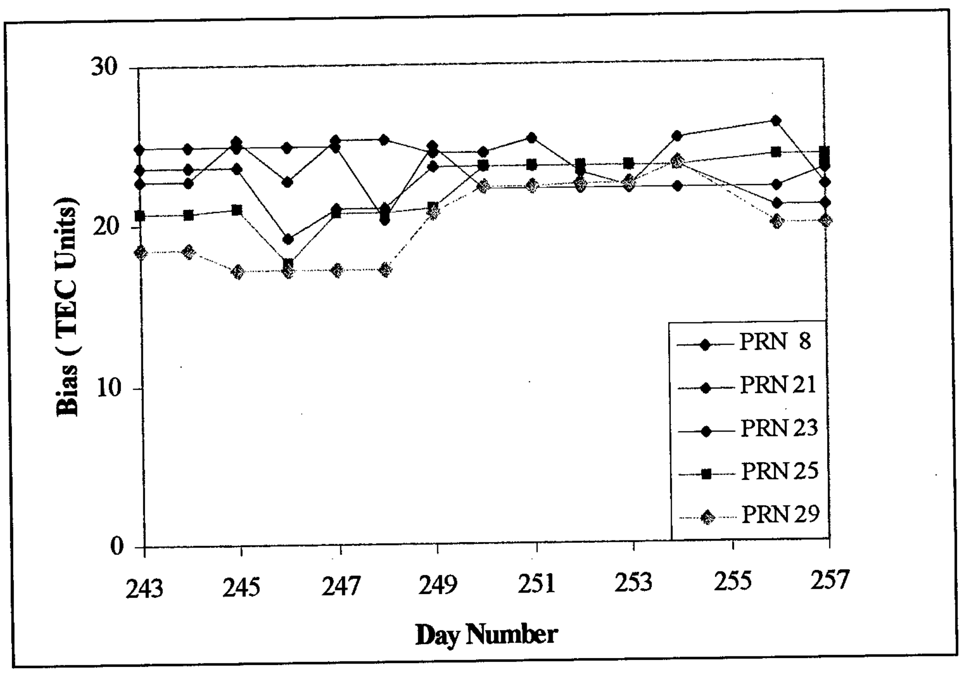

Fig. 17b. Sliding-median Bias values for Isabella during 20–22 UT from Method 3. Day 243 is Sept. 1, 1999

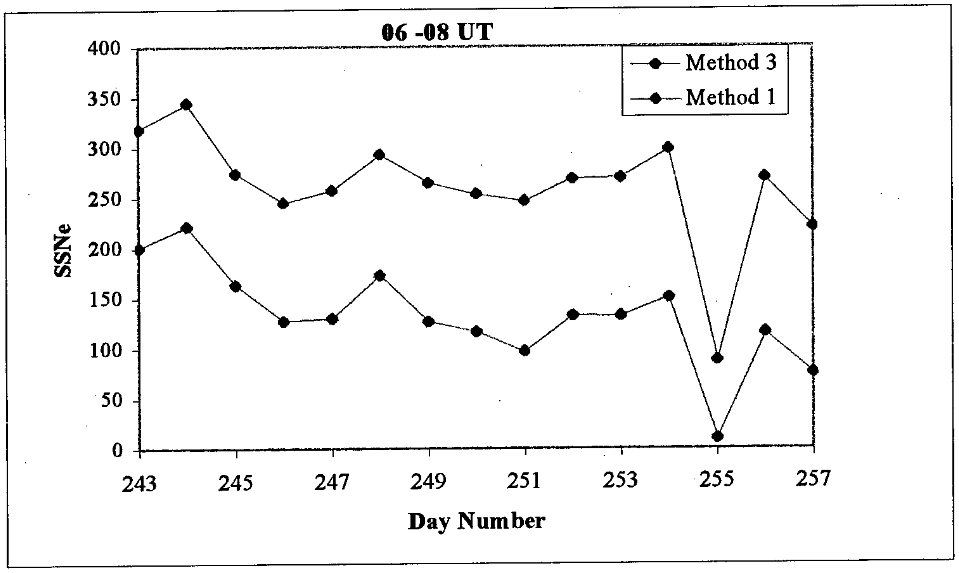

Fig. 18a. Recalculated RIBG SSN values for Isabella, using median biases from Methods 1 and 3 in Fig. 15.

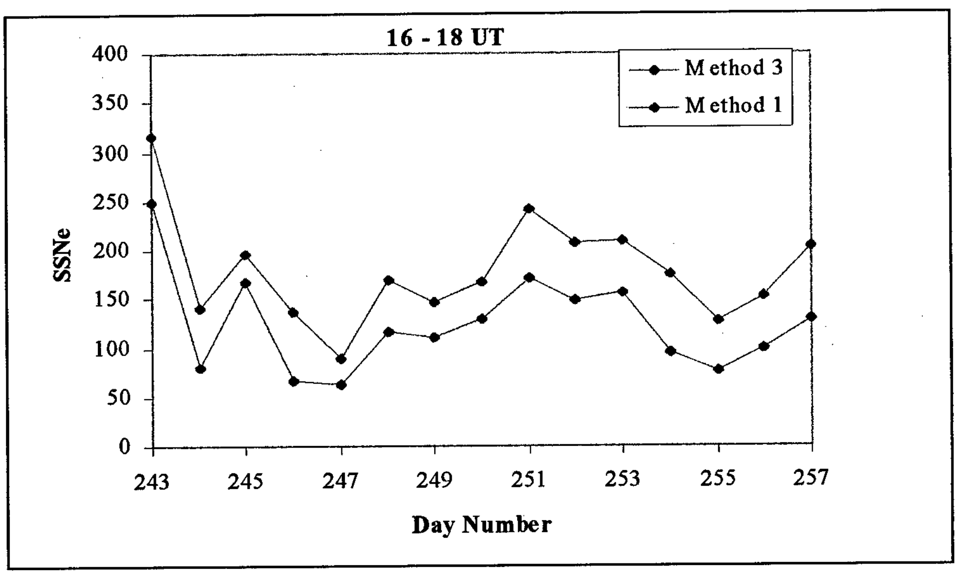

Fig. 18b. Recalculated RIBG SSN values for Isabella, using median biases from Methods 1 and 3 in Fig. 16.

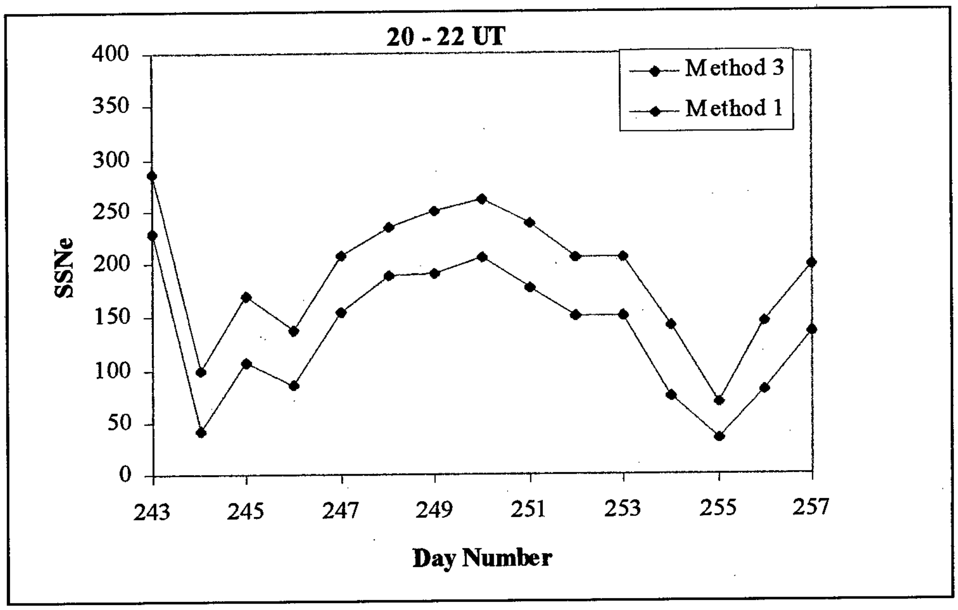

Fig. 18c. Recalculated RIBG SSN values for Isabella, using median biases from Methods 1 and 3 in Fig. 17.

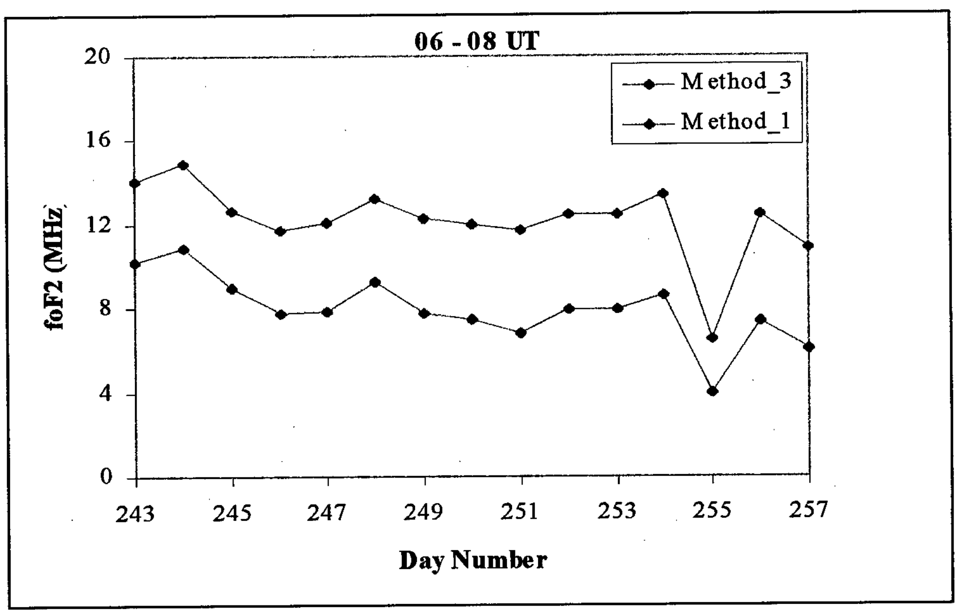

Fig. 19a. RIBG-predicted values of foF2 at Isabella, using Fig. 18a. Method 3 predictions should be more reliable.

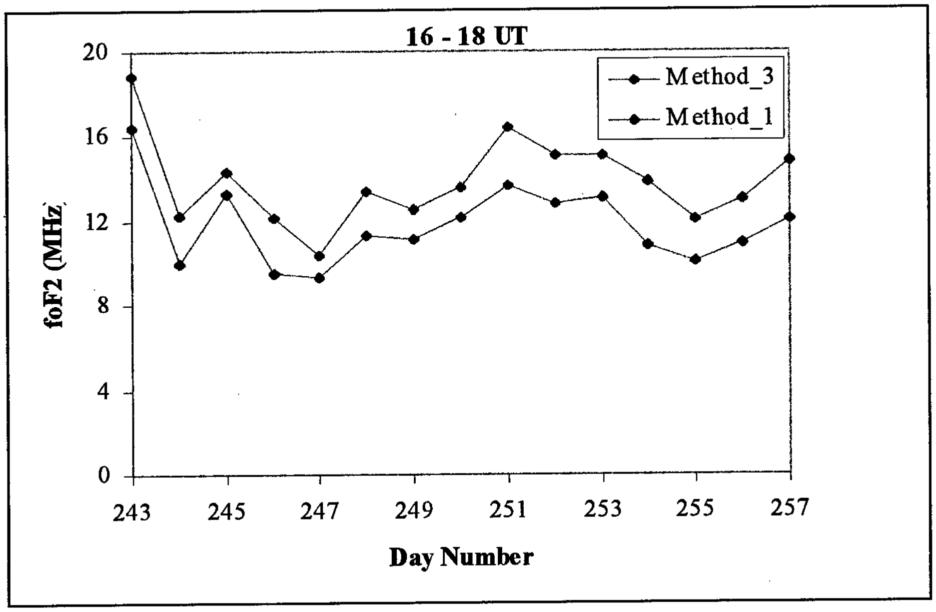

Fig. 19b RIBG-predicted values of foF2 at Isabella, using Fig. 18b. Method 3 predictions should be more reliable.

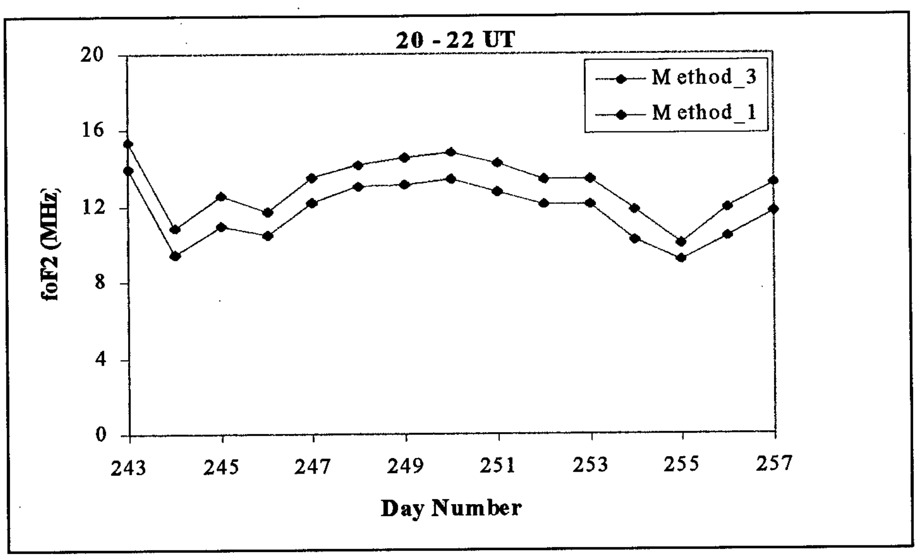

Fig. 19c. RIBG-predicted values of foF2 at Isabella, using Fig. 18c. Method 3 predictions should be more reliable.

Long-term Variation of Differential Bias Values. We have tracked weekly median biases for a 14-month period for Isabella, encompassing the two Puerto Rico experiments of June, 1998 and September, 1999. We also include an intermediate month, March, 99, in an attempt to discern the long-term variation of Bias values. Since modern GPS receivers used by the military for precise navigation are or will be dual frequency receivers, it is important to have accurate Bias values, as from Method 3, so that the ionospheric contribution can be successfully removed for precise position determination. Under these circumstances, the ionospheric contribution, whether it includes pathological conditions are not, is removed by simple manipulation of the two-frequency data; presumably the phase data (once the integer ambiguity bias has been removed), since phase data does not suffer the multipath contribution. Table 4 shows the Method 3 weekly median differential Bias values from the three different time periods. We do not see a systematic trend. Instead, the values seem to fluctuate on a smaller time scale, by as much as 10 TECU. Subtraction of biases in a column of Table 4 gives differences of satellite differential Bias values, with the receiver contribution canceling out, and these behave similarly, so that we cannot assign blame for the fluctuations to the much less expensive receiver clocks. It appears that one should routinely determine median differential Bias values on a time scale of weeks, rather than months. The sliding-weekly-median bias is apparently satisfactory for this purpose.

Table 4. Method 3 Differential Bias Values for Isabella for Three Different Time Periods

Sat.	23 – 29 Jun. 1998	1 - 6 Mar. 1999	31 Aug. - 6 Sep. 1999
PRN 4	16.7	26.1	22.9
PRN 7	28.3	23.2	25.4
PRN 10	31.3	26.7	31.1
PRN 24	26.9	27.4	31.5

Scientific Objective (2): Demonstrate improved ionospheric specification by suitably amending the ionospheric model. This project has concentrated on a practical, effective way to process GPS data for ionospheric specification. The RIBG (or ITRAY) ionospheric model has not been amended, but the way in which this model interacts with GPS data to update itself and to update an AIPM has. A particular concern was the determination of valid hardware differential Bias values, which are subtracted from shifted differential phase pseudorange data, to obtain accurate slant TEC data, which can assist the development of an AIPM. An AIPM would update itself by determining its own driving parameters that best fit this slant TEC data and any other data available for the assimilation.

Scientific Objective (3): Develop a data fusion scheme, combining GPS with other data sets. We have been particularly concerned with combining data sets from different GPS

stations for ionospheric specification in a region spanned by the receivers. At a minimum, the driving parameters of the ionospheric model used for interpolation throughout the region should not vary in a discontinuous way with position, when there are no major irregularities present. We have achieved a method for doing it, which is apparently superior to others being used, based on the use of the RIBG ionospheric model and weekly sliding-median differential Bias values, determined from DIT/RIBG processing of GPS data. There is no reason to suspect that this cannot be extended to fusion of various data types for updating an AIPM.

Tasks Completed:

(1): Completion of the algorithm for DIT/RIBG processing of GPS data to obtain relatively accurate differential hardware biases that can be subtracted from shifted differential phase pseudorange data to obtain relatively accurate slant TEC for input to an assimilating ionospheric model (AIM).
(2): Use of the weekly median bias solution in recalculation of the RIBG driving parameter that exhibits transportability of the ionospheric model driving parameter from one GPS station to an adjacent one, a necessary property of combining data from a network of GPS receivers for accurate regional ionospheric specification.
(3): Comparison with the traditional GPS data-processing technique, based on a thin isotropic shell mapping function for conversion of vertical TEC to slant TEC, to demonstrate the superior accuracy of our technique, based on extensive processing of data from the Puerto Rico experiments for June, 1998 and September, 1999. This is based on transportability of the SSN solution for RIBG to adjacent GPS stations and comparison of RIBG-predicted foF2 values with Puerto Rico ionosonde measured foF2 values.
(4): Formulation of the weekly sliding-median technique for differential Bias determination and demonstration of its effectiveness for processing the September, 1999 Puerto Rico data.
(5): Tabulation of our best estimates of median differential Bias values for both Puerto Rico experiments, which can be used in post-processing to extract slant TEC data for the first three weeks of September, 1999 from the Isabella receiver
(6): Extensive predictions of Isabella foF2 data for the September, 1999 experiment, which can be compared to Puerto Rico ionosonde data, when it becomes available.
(7): Data collection for the long-term variation (several months) of differential Bias values, indicating the importance of updating these values on a much smaller time scale (e.g., weekly).

Results/Conclusions:

(1): A RIBG/DIT technique (Method 3 in the text) is available to process GPS dual-frequency data, to provide state-of-the-art hardware differential biases and ionospheric TEC data for an AIM development and deployment.
(2): The RIBG/DIT software for GPS data processing is robust and yields both the hardware biases, the associated measured ionospheric TEC data, and RIBG driving parameters for use in ionospheric specification by RIBG. It appears that sufficient

accuracy is available from this method, but often not from the traditional ionospheric shell model method.

(3): The use of AIM for ionospheric specification is illustrated by the use of RIBG, updated by GPS data from a network of receiver, as discussed in the text. The key is to use a valid ionospheric model, determine its driving parameters reliably near the data sources (e.g., GPS receivers, using our median differential Bias values), and then interpolate the driving parameters, as necessary for regional ionospheric specification. This now appears feasible with a reasonable number of GPS receivers. Fusion with UV airglow and other data types is the next step to consider.

Impact for Science: A major objective is global real-time specification of the ionospheric electron density distribution for use in space weather forecasts and nowcasts for radio and electrical systems, ionospheric compensation in various types of radio systems, some requiring this information to meet ambitious performance goals, and as a database for developing solar-terrestrial physics. The final objective will be met with a data-driven, ionospheric model, where all the algorithms involved are of sufficiently high quality to provide requisite accuracy. We have concentrated on the processing of GPS data for this purpose, due to the future, commercially driven expansion of the GPS global data set on land and in space. The GPS receiver is a robust remote sensor of the ionosphere, because it senses the entire electron distribution at a reasonable price. Our techniques are leading to a successful exploitation of the GPS data set for accomplishing the above objective. Further, the RIBG model is a simple, practical testbed for evaluating progress in the development of a more complicated AIM for this purpose; particularly since RIBG is a prototype of an assimilating ionospheric propagation model (AIPM), which may ultimately be used to generate products for radio system customers and for the advancement of radio and remote sensing science.

Relationship to Other Programs or Projects: We believe that our GPS processing techniques will contribute significantly to the development and deployment of a GPS data source for an Assimilating Physical Ionospheric Model (AIM), itself under development in a large multiagency funded project. It is hoped that some of our techniques will facilitate the development of AIM, including its ultimate combination with a radio propagation model, to form an Assimilating Ionospheric Propagation Model (AIPM) for atmospheric compensation in radio systems. Of course, there is a spate of commercial and military applications for this capability. The use of GPS-updating and other updating methods for RIBG has already been applied or is being evaluated for radio surveillance and commercial GPS systems.

A DoD-wide exploitation of GPS technology is underway, to upgrade our military capability. Accurate, autonomous navigation of military forces and equipment is a priority. The military GPS receiver will be of the two-frequency type, to remove the ionospheric error from navigation (e.g., 10-20 m.). Once differential Bias values are determined for each receiver, the ionospheric contribution can be simply determined and removed at any time. This helps, but does not totally solve the navigation problem. It is desirable to use phase data for navigation, in order to avoid the multipath contribution. However, this necessitates removal of the phase integer ambiguity error from the data.

There are techniques for doing this, but they require knowledge of the ionospheric contribution or a good model estimate, which again depends on having an accurate differential Bias. The detailed method for accurate navigation is something we can develop, based on our experience with this project. The objective is accurate navigation and location of personnel, equipment, and threats, for the situations that require high accuracy.

There is further requirement for accurate ionospheric compensation in connection with DoD space radio systems. Use of a GPS receiver network to update RIBG or an AIPM for this purpose is one option. Or, simply updating a model like RIBG from the system data itself is an option. This project has helped us refine tools that can be exploited for this purpose. SAR is an example of a frequency-agile military system that provides ionospheric information as a byproduct.

Transitions Accomplished and Expected:

This project has helped to define the use of GPS data for AIM updating and ionospheric specification. The present level of performance has been defined and the problems elucidated. Techniques have been identified to improve performance, and a software module has been developed for implementation of GPS data processing by AIM developers. It is expected that the GPS data-processing techniques and accuracies will improve to the extent that the software module will be useful for development of the AIM system, at least the component related to GPS data fusion. Further, GPS can be used as a sanity check and as a complementary data source, relative to other sources in the AIM data fusion effort. An efficient data-driven ionospheric propagation model is of interest for performance enhancement of DOD radio surveillance systems, and will probably be transitioned to these systems. Our techniques are relatively accurate for ionospheric compensation in GPS navigation systems and for providing relatively accurate corrections for DGPS systems, and the techniques are improving. Hence, we expect commercial and military interest in our GPS techniques, many of which have been developed under ONR funding.

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November 3, 1999
99L-B2229/020
CCS# 99-2905

Mr. Tremayne Terry
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Aviation Applied Technology Directorate
U. S. Army Aviation and Missile Command
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Fort Eustis, VA 23604-5577

BOEING

Dear Mr. Terry:

Subject: Contract DAAJ09-94-G-0009, D.O. D901, Aircrew Maintenance Interface Debrief System (AMIDS), Submittal of CDRL A003 Final Report

McDonnell Douglas Helicopter Company Systems (MDHS), is pleased to submit the Final Report for the AMIDS program. Three (3) copies are provided: two (2) printed and one (1) on CD disc in accordance with Contract Data Requirements List (CDRL) for the subject contract. As required for the A003 Final Report submittal, MDHS encloses the DD Form 250. Please return the original DD Form 250 upon signing to the attention of the undersigned. According to our records, the submittal of this final report concludes all work to be performed under this contract.

In addition, two (2) printed copies of the Final Report are being forwarded to the Defense Technical Information Center in accordance with DFARS 252.235-7011.

Should further information be required, please contact the undersigned at (480) 891-7581 or via internet at linda.m.hubert@boeing.com.

Sincerely,

Linda Hubert

Linda Hubert
Contract Administrator
Development Contracts
The Boeing Company (Mesa)
M/S M530-B336

Enclosure: (1) Report Number USAAMCOM TR99-D-30
(2) DD Form 250, Shipment No.MES0002Z

cc: Defense Technical Information Center
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